OSCILLATORY FREE INDUCTION DECAY IN ANGULAR DISTRIBUTION OF NUCLEAR RADIATION

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A theoretical consideration of the free induction decay (FID) signal formation in the angular distribution of radiation, emitted by oriented nuclei after excitation by a long radiofrequency resonance pulse $t_p \gg T_2^*$, is carried out. The well-known theorem on the oscillatory FID signal is expanded for the case of second rank tensors.

Recently the spin echo and free induction decay (FID) were detected by observation of the change in anisotropy in the angular distribution of radiation, emitted by oriented nuclei [1]. Theoretical consideration of the observation of spin echo and FID signals in the angular distribution of nuclear radiation (ADNR) is of special interest, in particular when the spin system by a long pulse ($t_p \gg T_2^*$, where T_2^* is the inhomogeneous dephasing time) is being excited. The investigation of the oscillatory behaviour of the FID under condition of strong inhomogeneity for a two-level system, observed in NMR or in optical resonance experiments has been carried out in refs. [2,3] and as a result the theorem on this phenomenon has been formulated. In the present paper the multilevel nuclear spin system I and oscillatory FID signal in ADNR is theoretically considered, and the theorem is expanded for the case of higher rank tensors ($\lambda > 1$), observed in ADNR experiments. The possibility of an oscillatory FID signal in the case of axial geometry of ADNR experiment, when an extra $\pi/2$-pulse is used to restore the initial axial symmetry of the nuclear spin system and to allow exploration of the spin system dynamics in the perpendicular plane [1], is investigated.

The statistical tensors ρ_q^λ, connected with the density matrix of the nuclei I by Clebsch–Gordon coefficients may be represented in the form [4]

$$\rho_{q_2}^{\lambda_2}(t_2) = \sum_{q_1,\lambda_1} G_{\lambda_1\lambda_2}^{q_1q_2}(t_2 - t_1)\rho_{q_1}^{\lambda_1}(t_1)\,, \tag{1}$$

where $G_{\lambda_1\lambda_2}^{q_1q_2}(t_2 - t_1)$ are the perturbation factors (PFs), defined by the interaction hamiltonian on the definite time interval $t_2 - t_1$, here $0 \leqslant \lambda \leqslant 2I$, $-\lambda \leqslant q \leqslant \lambda$. We obtained the PF, for the spin system I, excited by a long pulse $t_p \gg T_2^*$, when the initial orientation of nuclei is defined by $\boldsymbol{k}_1(\theta_1, \varphi_1)$ and the direction of nuclear radiation registration is $\boldsymbol{k}_2(\theta_2, \varphi_2)$:

$$\langle G_{2\,2}^{1\,-1}\,\mathrm{e}^{-\mathrm{i}(\varphi_1+\varphi_2)} + G_{2\,2}^{-1\,1}\,\mathrm{e}^{\mathrm{i}(\varphi_1+\varphi_2)}\rangle$$
$$= \left\langle\left(\frac{\cos 2y(1+x^2)^{1/2}}{(1+x^2)^2} - 4\,\frac{\cos y(1+x^2)^{1/2}}{(1+x^2)^2} + 3\,\frac{\cos y(1+x^2)^{1/2}}{1+x^2} - 3\,\frac{x^2}{(1+x^2)^2}\right) \times \cos bx\,\cos(ab+\alpha)\right\rangle\,, \tag{2a}$$

$$\langle G_{2\,2}^{2\,-2}\,\mathrm{e}^{-2\mathrm{i}(\varphi_1+\varphi_2)} + G_{2\,2}^{-2\,2}\,\mathrm{e}^{2\mathrm{i}(\varphi_1+\varphi_2)}\rangle$$
$$= \left\langle\left(\frac{1}{4}\,\frac{\cos 2y(1+x^2)^{1/2}}{(1+x^2)^2} - \frac{\cos y(1+x^2)^{1/2}}{(1+x^2)^2} + \frac{3}{4}\,\frac{1}{(1+x^2)^2}\right)\cos 2bx\,\cos 2(ab+\alpha)\right\rangle\,, \tag{2b}$$

where $y = \omega_1 t_p$, $b = \omega_1(t - t_p)$, $a = \omega_0/\omega_1$, $x = \Delta\omega_j/\omega_1$, $\alpha = \omega_0 t_p + 2\Delta - \varphi_1 - \varphi_2$; $\omega_0, \omega_1, \Delta$ are frequency, amplitude and phase of the pulsed field, the bracket $\langle\ \rangle$ denotes an average over te inhomogeneous line

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